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Q^2 evolution studies of nuclear structure function F_2 at HERA

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Nuclear modification of the structure function F_2 has been an interesting topic since the discovery of the EMC effect in 1983. Although most studies discuss x dependence of the modification, Q^2 dependence becomes increasingly interesting. It is because the NMC measured Q^2 variations of the ratio F_2^A/F_2^D [1]. Furthermore, it is found recently that there exist significant differences between tin and carbon Q^2 variations, $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2] \neq 0$ [1]. However, the NMC data are taken in the limited small Q^2 range at small x, so that they are not sufficient to test nuclear Q^2 evolution. The Q^2 dependence is important for understanding perturbative QCD in nuclear environment, and the future HERA nuclear program can make important contributions to this interesting topic.

The Q^2 dependence of structure functions can be calculated by using the DGLAP equations. They have been successful in describing many experimental data. However, as it becomes possible to reach the small x region by high-energy accelerators, it is necessary to investigate the details of small x physics. The longitudinal localization size of a parton exceeds the average nucleon separation in a nucleus in the small x region ($x < 0.1$). It means that partons in different nucleons could interact in the nucleus, and the interaction is called parton recombination (PR). This mechanism is used for explaining nuclear shadowing. There are a number of studies on the recombinations. Among them, we employ the evolution equations proposed by Mueller and Qiu. They investigated gluon-gluon recombination effects on the evolution. The DGLAP and PR evolution equations are given by (see Ref. [2] for the details)

$$\frac{\partial}{\partial t}\, q_i\,(x,t) \;=\; \int_x^1 \frac{dy}{y}\, \left[\, \sum_j P_{q_i q_j}\left(\frac{x}{y}\right)\; q_j\,(y,t) \;+\; P_{qg}\left(\frac{x}{y}\right)\; g\,(y,t)\,\right] + \left(recombination\ terms\ \propto\ \frac{\alpha_s A^{1/3}}{Q^2} \right)\ , \quad (1a)$$

$$\frac{\partial}{\partial t}\, g\,(x,t) \;=\; \int_x^1 \frac{dy}{y}\, \left[\, \sum_j P_{g q_j}\left(\frac{x}{y}\right)\; q_j\,(y,t) \;+\; P_{gg}\left(\frac{x}{y}\right)\; g\,(y,t)\,\right] + \left(recombination\ terms\ \propto\ \frac{\alpha_s A^{1/3}}{Q^2} \right)\ , \quad (1b)$$

where the variable t is defined by $t = -(2/\beta_0)\ln[\alpha_s(Q^2)/\alpha_s(Q_0^2)]$. In the PR evolution case, there is an extra evolution equation for a higher-dimensional gluon distribution. The first two terms in Eqs. (1a) and (1b) describe the process that a parton

the NMC data in Fig. 1 at x=0.0085 [2]. The initial distributions at Q_0^2=0.8 GeV^2 in the nucleon and the calcium nucleus are taken from Ref. [3]. In Fig. 1, the dotted, solid, and dashed curves are obtained in the leading-order (LO) DGLAP, next-to-leading-order (NLO) DGLAP, and NLO evolution equations with parton-recombination contributions respectively (Λ=0.2 GeV and N_f=3). As shown in the figure, NLO and recombination contributions to the ratio are conspicuous at such a small x. If we evolve F_2 from Q_0^2=0.8 GeV^2, the recombination effects are larger than the NLO ones. It is interesting to find such large recombination contributions in Fig. 1. However, the recombination cannot be tested at this stage because we do not have the data in the wide Q^2 region at small x. The future HERA nuclear program should be able to study the large Q^2 region, so that the parton recombination mechanism could be tested.

Figure 1: Q^2 variation of F_2^{Ca}/F_2^D.

Next, Q^2 evolution differences in various nuclei could also be investigated at

Figure 2: Nuclear dependence in Q^2 evolution of F_2.

F_2 in tin and carbon nuclei is investigated in Ref. [4]. As the input distributions, we employ those in Ref. [3]. F_2 is evolved by using LO DGLAP, NLO DGLAP, and PR equations with the help of a computer program in Ref. [2]. Calculated results for $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2]$ at Q^2=5 GeV^2 are compared with the NMC data. The DGLAP evolution curves agree roughly with the experimental tendency, but the PR results are significantly different from the data. However, it does not mean that the recombination mechanism should be ruled out because there exists an unknown parameter K_{HT} associated with the higher-dimensional gluon distribution in the recombination. In order to discuss the validity of the PR evolution, the constant K_{HT} must be evaluated theoretically.

In this way, the NMC experimental result $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2] \neq 0$ could be essentially understood by the difference of parton distributions in the tin and carbon nuclei together with the ordinary DGLAP evolution equations. However, we find an interesting indication that "large" higher-twist effects on the Q^2 evolution could be ruled out. As shown in Fig. 2, there are large differences among three evolution results at small x ($\approx 10^{-4}$). The future HERA program can study nuclear dependence of the Q^2 evolution ($\partial[F_2^A/F_2^D]/\partial[\ln Q^2]$) in this small x region, and it provides us crucial information on recombination effects and on higher-order α_s effects.

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